



Designation: D6026 – 21

# Standard Practice for Using Significant Digits and Data Records in Geotechnical Data<sup>1</sup>

This standard is issued under the fixed designation D6026; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope\*

1.1 Using significant digits in geotechnical data involves the processes of collecting, calculating, and recording either measured values or calculated values (results) or both. This practice is intended to promote uniformity in recording significant digits for measured and calculated values involving geotechnical data.

1.2 The guidelines presented are industry standard and are representative of the significant digits that should be retained in general. The guidelines do not consider material variation, the purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives, and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations.

1.3 It is beyond the scope of this practice to consider significant digits used in analysis methods for engineering design.

1.4 This practice accepts a variation of the traditional rounding method that recognizes the algorithm common to most hand-held calculators and computers, see 6.2.3. The traditional rounding method (see 6.2) is in accordance with Practice E29, ASTM Manual 7, or IEEE/ASTM SI 10.

NOTE 1—Calculators and computers often present and use many digits in their output and calculations, which may not all be significant. It is the responsibility of the programmer and user to make sure that the measured and calculated values are handled, interpreted and reported properly using these guidelines.

1.5 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of*

*a project's many unique aspects. The word "Standard" in the title means only that the document has been approved through the ASTM consensus process.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2435/D2435M Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D4186/D4186M Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E456 Terminology Relating to Quality and Statistics

E833 Terminology of Building Economics

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): *The Modern Metric System*

MNL7 ASTM Manual 7 on Presentation of Data and Control Chart Analysis

## 3. Terminology

3.1 *Definitions*—For common definitions of soil and rock terms in this standard, refer to Terminology D653.

3.2 This terminology standard contains many definitions that are applicable to this standard in a grouping named Measurement Grouping. These terms are: accuracy, bias, estimation, meaningful number/digit or significant number/digit, observation/observed value or data point/recorded value, precision, resolution or readability, sensitivity, signal noise or noise.

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.91 on Standards Development and Review.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

\*A Summary of Changes section appears at the end of this standard

3.3 Other definitions that are relevant to this topic of data management or presentation or both are given below.

#### 3.4 Definitions:

3.4.1 *significant digit/number/figure, n*—any of the integers one through nine and zeros except leading zeros and some trailing zeros.

3.4.1.1 *Discussion*—Zero is a significant digit if it comes between two non-zero integers.

3.4.1.2 *Discussion*—Zeros, after a decimal point and leading the first nonzero digit of a number, indicate the order of magnitude only and are not significant digits. For example, the number 0.0034 has two significant digits.

3.4.1.3 *Discussion*—Zeros trailing the last nonzero digit for numbers represented with a decimal point are significant digits. For example, 4.00 and 4.01 have three significant digits.

3.4.1.4 *Discussion*—The significance of trailing zeros for numbers represented without the use of a decimal point can only be identified from a knowledge of the source of the value.

3.4.2 *sensitivity analysis, n*—a test of the outcome of an analysis by altering one or more parameters from an initially assumed or initial test value(s).

3.4.2.1 *Discussion*—Sensitivity analyses are often related to the design process, but not exactly applied in that design process. A sensitivity analysis might include how measured shear strength or hydraulic conductivity varies with molding water content or percent compaction, or both.

3.4.3 *test result, n*—the value obtained by applying a given test method, expressed as a single measurement or a specified combination of a number of measurements, calculations, or any combination.

3.4.4 *variability analysis, n*—the determination of the variation in test results or property values (index or engineering) within a given boundary condition(s).

3.4.4.1 *Discussion*—A variability analysis might include how a given property varies with depth.

3.5 Data Processing Grouping, the following four definitions cover how one should cover the collection or processing of test data.

#### 3.6 Definitions:

3.6.1 *measurement or measured value, n*—the act or process of quantifying a physical measurement; such as time, acceleration, dimension (length, diameter, depth, and circumference), force, mass, pressure, and velocity. This process would also include in many test methods the calculation of basic quantities which do not require any judgment, such as water content, void ratio, density, unit weight, stress, and strain. See *read or reading* and *determination*.

3.6.1.1 *Discussion*—A typical example is: “Measure and record the height, diameter, and mass of the test specimen and calculate its density, in accordance with the requirements specified in this standard. or simply state Measure the density or water content.” However, in some standards, the apparatus specified internally makes the necessary measurements and calculations and displays a test result(s), such as a nuclear gauge. In such cases, an example is: “Measure and record the

total density and water content using a nuclear gauge meeting the requirements specified in the apparatus section of this standard.”

3.6.2 *read or reading(s), n*—the act or process of quantifying an instrument(s); such as dial gauge, burette, multimeter, transducer, or data acquisition system. See *observation/observed value or data point/recorded value*, mentioned above in 3.2.

3.6.2.1 *Discussion*—A typical example is: “Read and record the dial gauge measuring the change in the height of the test specimen during consolidation at time intervals and meeting the requirements specified in this standard.” For usage of a data acquisition system: “Read and record, at intervals specified in this standards the transducer’s measuring the applied axial force, axial displacement, and cell pressure applied to the test specimen along with the internal pore-water pressure in the test specimen.”

3.6.3 *calculation or calculated value, n*—the act or process of using an equation which converts a measured value(s) into another define quantity, without interpolation.

3.6.3.1 *Discussion*—Some examples being: converting diameter to area or diameter and height to volume, or mass, height, and diameter to density.

3.6.4 *determine or determined value, n*—the act or process of quantifying measured or calculated or both value(s) into another value(s) that requires judgment based on education, training, or experience.

3.6.4.1 *Discussion*—A simplified example is: “Determine the preconsolidation stress based on the test results from a consolidation test (either Test Method **D2435/D2435M** or **D4186/D4186M**).”

## 4. Summary of Practice

4.1 The user follows a set of guidelines that allow making decisions and actions that promote uniformity in the retention, rounding, and recording of significant digits for measured and calculated values involving geotechnical data.

4.2 The programmer and user make sure that the numbers are handled, interpreted, and reported accordingly for any specific requirements and caveats in the geotechnical standard for which the data were obtained.

## 5. Significance and Use

5.1 The guidelines presented in this practice for retaining significant digits and rounding numbers may be adopted by the using agency or user. Their adoption should generally be used to calculate and record data when specified requirements are not included in a standard.

5.2 While this practice originated when most geotechnical data were manually collected and recorded on data forms, tables, or into computers, the use of digital acquisition, calculations, and reporting of data has become more common. When calculators and computers are used for data collection, the significant digits may not meet the requirements specified in this standard. Nevertheless, their use shall not be regarded as nonconforming with this practice.

5.3 The guidelines presented herein should not be interpreted as absolute rules but as guides to calculate and report observed or test data without exaggerating or degrading the precision of the values.

5.3.1 The guidelines presented emphasize recording data to enough significant digits or the number of decimal places to allow sensitivity and variability analyses to be performed.

**6. Guidelines for Rounding Numbers in Calculating and Recording Data**

6.1 *General Discussion*—Rounding data avoid the misleading impression of precision while preventing the loss of information due to coarse resolution. Any approach to retention of significant digits of necessity involves some loss of information; therefore, the level of rounding should be selected carefully considering both planned and potential uses for the data. (See Practice E29.)

6.2 *Rounding Numbers*—When a numerical value is to be rounded to fewer digits than the total number available, use the following procedure shown in Table 1, per Practice E29, ASTM Manual 7 on Presentation of Data and Control Chart Analysis, or IEEE/ASTM SI 10:

6.2.1 The rounded value should be obtained in one step by direct rounding of the most precise value available and not in two or more successive rounding steps. For example, 89 490 rounded to the nearest 1000 is at once 89 000. It would be incorrect to round first to the nearest 100, giving 89 500 and then to the nearest 1000, giving 90 000.

6.2.2 The same rule applies when rounding a number with many digits to a number with a few digits. This typically occurs when using a computer or calculator that displays the computed answer as ten or more digits, and the answer is to be recorded to a few digits. For example, the number 2.34567 rounded to two significant digits would be 2.3.

6.2.3 Calculators and computers, in general, do not follow all the rules given in 6.2, (that is, only rounding up odd digits followed by a five, while even digits stay the same (2.55 to 2.6 or 2.45 to 2.4)) and generally always round up. Recognizing the widespread use of calculators and computers that always round up, their use shall not be regarded as nonconforming with this practice. When carrying out computer calculations, do not perform intermediate rounding. Computations performed with spreadsheets or computer programs hold real numbers in double precision, about 17 digits, so concern about rounding during computation is largely unnecessary. Rounding of calcu-

lator and computer values is done when reporting the test result after all calculations have been completed. See Note 1.

6.2.4 The numbers to be reported are rounded at the end of calculations to the appropriate number of significant digits, not prior to the calculations. (See 6.4.)

6.3 *Recording Measured Data*—When recording measured values, as in reading marks on a burette, ruler, or dial, record all known digits exactly, plus one digit, which may be uncertain due to estimation.

6.3.1 When the measuring device has a vernier scale, record the last digit from the vernier.

6.3.2 The number of significant digits displayed by a digital display or printout from an instrument should not be greater than, but equal to the precision of the sensor to which it is connected. However, most digital apparatus record and/or display digits that are affected by “noise.” Therefore, there needs to be some form of documentation specifying which digits are meaningful/significant. For example, one could tape over displayed digits that are not meaningful or in the heading of tabulated data, one could write/type “1st four digits are sufficient.”

6.4 *Calculation of Measured Data*—When measured values are used in the calculations, avoid rounding of intermediate quantities. As far as practicable with the calculation device or data sheet/form used, or both, carry out calculations exactly as they occur (no reduced digits) and round the final value/result.

6.5 *Recording Data*—The recorded data should conform to instructions in the respective standards. For example, recording the computed water content values used in measuring the liquid and plastic limits of a soil on the data sheet/form to the nearest 0.1 %, see Table A1.1. While the liquid and plastic limits are recorded, reported, or summarized to the nearest whole number and the percent designation is omitted.

6.5.1 If the number of significant digits or number of decimal places in the measured and calculated value(s) is not specified in the respective standard, then one may use the following approach. Use Table A1.1 to select the number of significant digits or number of decimal places in the calculated value(s). Using that value(s) and the rules of significant digits as described in Section 7, select the required significant digits or number of decimal places for the measured value(s).

6.5.2 If a standard has a conflict between the measured and calculated value(s) related to significant digits or the number of decimal places, then use the following criterion. The criterion specified for calculated value(s) should govern how the measured value(s) is selected and recorded.

**TABLE 1 Procedures and Examples of Rounding to Two Significant Digits**

When the first digit beyond the last place to be retained is:	The digit in the last place retained is:	Examples
<5	unchanged	2.445 to 2.4
>5	increased by 1	2.464 to 2.5
Exactly 5	increased by 1 if it is odd unchanged if it is even	2.55 to 2.6 or 2.45 to 2.4
5 followed only by zeros	same as above for exactly 5	2.5500 to 2.6 or 2.4500 to 2.4

**7. Guidelines for Retaining Significant Digits in Calculating and Recording Data**

7.1 Upon completion of mathematical calculations, use the following rules as guidelines to select the proper number of significant digits or decimal places of rounded numbers.

7.1.1 The rule when multiplying or dividing is that the result shall contain no more significant digits than the value with the smaller number of significant digits. Examples include:

7.1.1.1  $11.38 \times 4.3 = 49$ , since the factor 4.3 has two significant digits.

7.1.1.2 Calculate the volume,  $V$ , of an object having a base area,  $A$ , of 28.48 in.<sup>2</sup> and a height,  $h$ , of 6.12 in.,  $V = Ah = (28.48 \text{ in.}^2)(6.12 \text{ in.}) = 174 \text{ in.}^3$ , the answer to three significant figures in agreement with the height measurement.

7.1.2 The rule when adding or subtracting data is that the number of decimal places in the result is the same as in the number containing the fewest digits following the decimal. Examples include:

7.1.2.1  $11.24 + 9.3 + 6.32 = 26.9$ , since the last significant digit of 9.3 is the first following the decimal place, and 26.9 results by rounding the exact sum, 26.86.

7.1.2.2  $(926 - 923.4) = 3$ .

7.1.2.3  $(926 - 923.4)/4.3 = 0.6$ . Only one figure is significant since the numerator difference has only one significant digit. This is an important factor to consider when recording and checking a calculated value(s) that include a difference(s), see **Note 2**.

**NOTE 2**—Typical examples of calculated values which include a difference(s) are water content, void ratio, deformation, degree of saturation, and specific gravity.

7.1.3 The rules for logarithms and exponentials are: digits of  $\ln(x)$  or  $\log_{10}(x)$  are significant through the  $n$ th place after the decimal when  $x$  has  $n$  significant digits. The number of significant digits of  $e^x$  or  $10^x$  is equal to the place of the last significant digit in  $x$  after the decimal. Examples include:

7.1.3.1  $\ln(3.46) = 1.241$  to three places after the decimal since 3.46 has three significant digits.

7.1.3.2  $10^{3.46} = 2\,900$  has two significant digits, since 3.46 is given to two places after the decimal.

7.1.4 When an exact count is used in a calculation with a number, the number of significant digits in the result is the same as the number of significant digits in the number. For example, the sum of two measurements was found to be 8.24 in. To find the average value, this sum must be divided by two. In this case, however, two is not a measurement but an exact count. Therefore,  $8.24 \text{ in.}/2 = 4.12 \text{ in.}$  Since 8.24 has three significant digits, the results also contain three significant digits.

7.1.5 To preserve accuracy in calculations using constants, or conversion factors with measured values, these non-measured values should retain at least one more significant digit than the measured number. For example, compute the inside circumference,  $C$ , of a mold having an inside measured diameter,  $d$ , of 6.025 in. The example calculation, having a constant value and a measured quantity, is:

$$C = \pi \times d = \pi \times (6.025 \text{ in.}) = (3.1416) \times (6.025 \text{ in.}) = 18.93 \text{ in.}$$

## 8. Guidelines for Applicability to Committee D18 Standards

8.1 If the rounding method of Section 6 is to apply to all data in the standard, and if all numbers expressed in the standard are to conform to the guidelines for significant digits as described in Section 7, then a statement similar to the following should be included in the scope of the standard:

8.1.1 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026 *unless superseded by this standard*. (Add the last italicized portion only if there are exceptions to Practice D6026.)

8.2 If results are to be compared with specification limits, a statement similar to the following should be included in the scope section of the standard:

8.2.1 For purposes of comparing a measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits. (Add this section only if it is applicable.)

**NOTE 3**—In preparing statement 8.2.1, the author might want to replace “measured or calculated value” with the appropriate name of that value(s) given in the standard.

8.3 If there is a report section, then the following caveats should be included if applicable:

8.3.1 *Scope Section of the Standard*—Add this caveat after the caveats for 8.1 and 8.2: The procedures used to specify how data are collected/recorded or calculated in this standard are regarded as the industry standard. Also, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, the purpose for obtaining the data, special purpose studies, or any considerations for the user’s objectives, and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

8.3.2 *Report Section of the Standard*—add the following caveat; The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.X1 and Practice D6026.

## 9. Keywords

9.1 data; data management; determination value; measurement value; recording data; rounding numbers; significant digits; test result